14.—LOAD CARRIED BY FLOOD WATERS IN THE SOUTH-WEST.

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INTRODUCTION.

The only published information about the quantity of material removed by rivers in south-western Australia appears to be an article by Teakle (6) on soil erosion in the northern agricultural areas and one by Finucane and Forman (2) on the load carried by the Swan River during the 1926 flood.

We record here some rough and ready measurements which have been made by students and staff of the Geological Department of the University of Western Australia since 1926 in the North Irwin and Swan Rivers, in the Chittering Brook, and in the Collie and Preston River systems which discharge into Leschenault Inlet. Much help has been received at various stages in the securing of these results from Messrs. S. E. Terrill, R. S. Matheson, P. Dunlop, E. S. Clarke, and S. J. Mayne, to all of whom we wish to record our thanks while absolving them from any responsibility for the form or content of this paper.

All the streams discussed are of the intermittent type; most of them flow only for a short time in the rainy season (winter) but those of the Collie-Preston system may continue running until early summer. In this paper the words ''flow,'' ''drain,'' etc., are, for the sake of brevity, used as if the streams were perennial.

The measurements were made in 1934, 1937, and 1939 during floods which followed exceptionally heavy rains. Widespread floods occurred in 1934 and 1939, but 1937 was a normal winter with a few heavy falls of rain.

The figures obtained indicate that, because of the infrequent opportunities which the rivers have of carrying a large load, the average rate of erosion in the south-western part of Australia is very much less than the world's average. This would, of course, have been expected in view of the topography, geology, and climate of the region. It seems worth while, however, to record the figures, while emphasising that they are only rough approximations to the true carrying capacity.

METHODS OF OBTAINING DATA.

In each case a part of the stream was selected which was most nearly straight and in which the channel was of approximately uniform cross section. In the Irwin and Chittering gaugings, cross sections at the two ends of the reach were obtained by measurements at 2-foot intervals; the area of the cross section in the *Table* is the mean of the two. In the other gaugings it was only possible to measure one cross section.

"Surface velocity" was calculated by averaging the rate of travel, over the comparatively straight reach, of a number of floats released at different distances from the banks. The figures so obtained and given in the *Table* are necessarily only the approximate rates of flow. One authority (4) suggests that 84% of the surface velocity is a fair average for the rate of movement of the whole body of water, but others consider that 75% only should be taken and we have used this latter figure in arriving at the column "mean velocity," from which the "load" has been calculated.

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The figures in the column "Load, gm. per litre" were obtained by evaporating to dryness a measured quantity (usually 2 to 3 litres) of the water, and weighing the residue; they therefore represent suspended plus dissolved matter. Samples in the North Irwin and Chittering were collected at various positions in the cross section both near the surface and near the bottom, since the amount of load will obviously differ in different parts of the cross section, but from the other streams it was only possible to collect samples from the middle near the surface. In these cases therefore the calculated load errs on the light side. A more serious under estimate moreover occurs in all the results, because no attempt could be made to calculate the quantity of material rolled along the stream bed, which in the more rapid streams was undoubtedly an important fraction of the load.

SUMMARY OF DATA.

The figures obtained as described and the calculations therefrom may be tabulated as follows:—

River Gauged.	Date.	Observed Results.			Mean* Velocity.	Discharge.	Load.	
		Cross Section.	Surface Velocity.	Load.				
		sq. ft.	ft. per sec.	gm. per litre.	ft. per sec.	cub. ft. per sec.	gm. per cu. ft.	Tons per day.
(1) †North Irwin	16–4–34	60	2·8	2·13	2·10	126	60·3	645
(2) Chittering Brook ...	20–5–37	12	3	0·0055	2·25	270	0·16	3·7
(3) Swan ...	11–3–34	...	...	0·0236	...	...	0·67	...
(4) Collie ...	13–8–39	2,518	1·5	0·225	1·13	2,840	6·36	1,530
(4a) Collie ...	30–8–39	2,683	1·33	0·21	1·00	2,683	5·94	1,360
(5) Brunswick...	30–8–39	666	2·85	0·13	2·14	1,430	3·68	450
(6) Preston ...	15–8–39	725	3	0·247	2·25	1,630	7·00	970
(7) Preston ...	28–8–39	600	1·33	0·207	1·00	600	5·86	300
(8) Preston ...	28–8–39	1,044	5	0·29	3·75	3,920	8·21	2,740
(9) Preston ...	28–8–39	840	5·6	0·214	4·20	3,530	11·9	3,570
(10) Ferguson...	15–8–39	70	5	0·22	3·75	263	10·6	238
(11) Leschenault Estuary at Pig Island near mouth	28–8–39	2,110‡	1·6	0·23	1·20	2,530	3·4	728

* Mean velocity is taken as 75 per cent. of observed surface velocity. † Numbers refer to position on map. ‡ Cross section given by the Public Works Department for low water mark; as the Estuary was in flood at the time of observation the cross section must have been greater than that given here, but there was no means of measuring it.

NOTES ON CONDITIONS IN INDIVIDUAL STREAMS.

1. *North Irwin.*—This stream rises about 20 miles above the place where it was gauged (for positions of streams and gauging places, see *Map*). From its source it flows over the Pre-Cambrian complex for 18 miles, and for the remaining two miles it flows through Permian shales and sandstones. A large part of this Permian country has been cleared of scrub and in late summer is almost devoid of vegetation; consequently heavy "autumn" rains like those of April, 1934, remove a very large quantity of soil and soft rocks.

Very heavy rain fell in the district during the first fourteen days of April, the official records being 5.20 inches at Nangetty and 5.63 inches at Mingenew. The usual April rainfall is 0.80 inches. This fall was therefore very exceptional for the time of the year, and those who saw the flood formed some conception of the large amount of "work" done by a stream which drains an area of approximately 150 square miles. It had been unfordable for several days before 16th April, when the samples were collected and was rapidly falling at the time of the gauging, consequently the calculated load is, apart from the inadequacy of the method, certainly an under-estimate.

Chittering Brook.—The Chittering is about 30 miles long and drains an area of about 335 square miles which is practically all in the Pre-Cambrian complex of schists, quartzites, and greenstones. Only the lower slopes of the valley are cleared, and as the cleared parts are under permanent grass, soil erosion is slight. The figures obtained for this stream are the nearest approach to the true rate of erosion in the western part of the "Great Plateau of Western Australia." All other streams gauged have part of their courses in more easily eroded rocks—hence the bigger "loads."

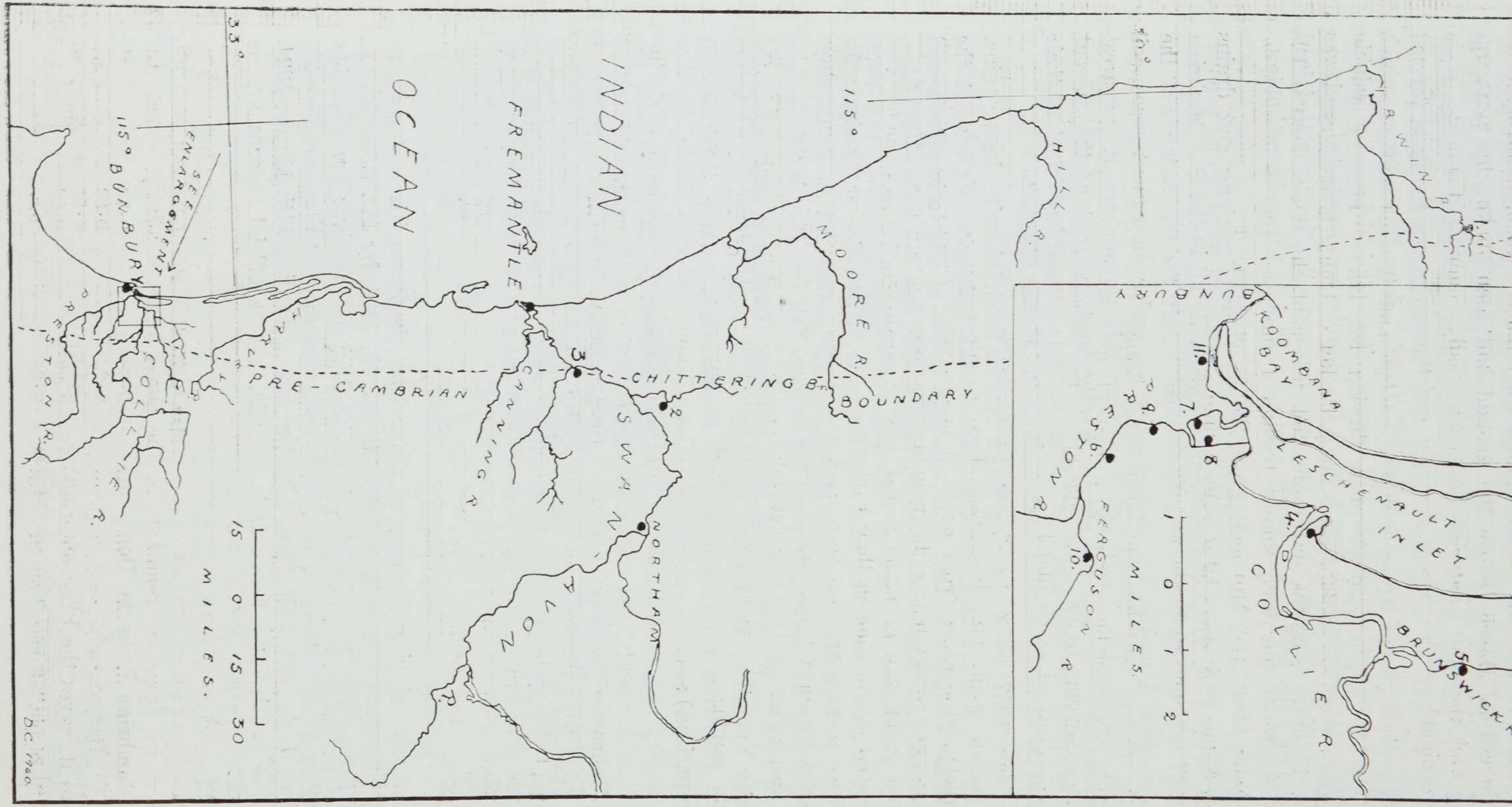
In May, 1937, the Chittering Brook was in flood following heavy rains. There are no daily rainfall records kept in the Chittering Valley but the month's rain for May in that year was 6.58 inches at Chittering Park, and 6.68 inches at Innaminka. Apparently most of this rain fell before 17th May, for the stream began to flood on 17th and was subsiding on 20th May, when the gauging was done. The rain was evidently patchy for at Toodyay the rainfall up to 17th May was 0.72 inches, but 2.29 inches fell on 18th, bringing the total to 3.91 inches, whereas the average fall for May is 2.87 inches.

A sample of the water from the Chittering Brook was analysed in the University Chemistry Department through the courtesy of Dr. G. A. Elliot, with the following result (an analysis of Mundaring water (5) is added for comparison) :—

	Chittering Brook.	Mundaring.
	ppm.	ppm.
Temporary Hardness	102 (as $CaCO_3$)	...
Permanent Hardness	29·2	...
Chlorides	227	210
So_4	50	27
Ca	13·5 and 11	10
Mg	18·3	18
Fe	8	tr.
SiO_2	n.d.	9

3. *Swan.*—A single sample of water from the Swan River at Barker's Bridge, Guildford, was collected on 11th March, 1934, by Mr. S. J. Mayne, but no figures for the velocity or cross section of the river are available. The amount of material carried was 0.0236 gramme per litre, considerably more than during the 1926 flood. On the days preceding 11th March, 1934, there were particularly heavy falls of rain. Some official records are as follows:—

	March, 1934.	Average March Rainfall.
	inches.	inches.
Northam	5·68	0·72
Toodyay	9·22	0·68
Guildford	5·19	0·61
Mundaring	4·93	0·96
" Belvoir," Upper Swan	3·85	n.r.



Map of part of the South-West of Western Australia, showing places where rivers were gauged and sampled, and Pre-Cambrian boundary. (Compiled from Western Australian Lands and Surveys map of part of the South Western Division of Western Australia, 15 miles to the inch; and Lands Department Litho. 411/80.)

This flood carried a heavier load than that of 1926, probably because it occurred in March before the ground had been soaked by more gentle rains, and therefore material was more easily removed than by a later winter flood.

The Swan-Avon River is shown on the Lands Department maps as rising near Wickepin, and therefore flowing for 125 miles over the Pre-Cambrian complex. Before reaching Barker's Bridge it has travelled for about 15 miles over the unconsolidated veneer of the Swan Coastal Plain. Actually water has been known to flow from near Menzies westwards to Northam where the Mortlock joins the Avon. The drainage area of the Swan-Avon is about 13,000 square miles, exclusive of the abovementioned occasional extension to the goldfields.

4. *Rivers entering the Leschenault Inlet, Bunbury.*—The Collie and Preston river systems, draining an area of approximately 1,400 square miles on the Darling plateau and coastal plains, discharge into the Leschenault Inlet at Bunbury (see map).

Leschenault Inlet is a wide shallow stretch of water which extends from its narrow outlet into Koombana Bay for about 10 miles to the north and parallel to the coast from which it is separated by a strip of sand dunes one-quarter to one-half mile in width. Although floods do not occur every year a great deal of material has been deposited just at the mouth of the river and in the wide shallow stretches of the inlet near by, for in the mouth a fairly large island has been built and in summer there is hardly sufficient water for even a small boat. The artificial channel, made many years ago, has also silted up and is practically useless for navigation purposes; nevertheless, the Collie river itself is very deep in places within a mile or two of its mouth.

The Collie river enters the coastal plain through a steep-sided, well-established valley south-east of Roelands. The river has built rich alluvial flats at Roelands and Burekup where terraces seem to indicate that there have been at least two small uplifts, of the order of 20 feet each. The river has cut deeply into its own alluvium, and is now depositing another series of flood plains. The Wellington dam, conserving water for irrigation purposes, is built in the valley some miles behind the scarp, and now reduces the amount of water reaching the plain. For part of its course the Collie flows over the Permian rocks of the Collie coalfield but the greater part lies in the Pre-Cambrian complex.

The Brunswick, a tributary of the Collie, drains the country north of the Collie, which it joins near its mouth. It has alluvial flats like those of the Collie, but smaller. Both of these rivers cross Pre-Cambrian country, which, away from the scarp, is covered by heavy laterite. Easily erodable soils have only developed on the valley sides and on the western side of the scarp.

The Preston river rises in the plateau country about 30 miles east of Donnybrook and flows in a wide valley, steep-sided on the north where the rocks are Pre-Cambrian, but of a more mature appearance on the southern side where there are remnants of the Donnybrook sandstone series. In the Pre-Cambrian rocks at Donnybrook, the valley is quite narrow and steep-sided. Immediately west of Donnybrook the river has deposited alluvium where it leaves the Pre-Cambrian; between Donnybrook and Boyanup it has eroded a mature valley in sandstones which are Permian or Triassic (3). In the coastal plain the river has cut steep banks, and no flood-plains occur until after it is joined by the Ferguson at Picton. Near its outlet the Preston meanders and is at grade; it has always flooded badly in winter near its mouth, but this has lately been remedied by cutting a more direct channel to the estuary.

Normally the Collie and Preston rivers are rather sluggish; water usually ceases to flow in the summer but is fairly brisk in winter.

Observations on the load carried by these rivers were made in August, 1939, when the rivers had been in flood for about a fortnight after continual heavy rain in July. Official rainfall records in the district for July and August are as follows:—

	July, 1939.	July Average.	August, 1939.	August Average.
	inches.	inches.	inches.	inches.
Bunbury	8·85	6·74	6·59	5·19
Collie	11·60	7·49	12·54	5·76
Brunswick	12·19	7·83	11·14	6·33
Donnybrook	8·95	7·74	10·72	6·05
Boyup Brook ...	5·34	4·92	5·88	4·10
Ferguson	9·83	n.r.	10·65	n.r.
Dardanup	10·90	n.r.	8·49	n.r.

The number of wet days at these towns during July and to the middle of August, 1939, are: Bunbury, 31; Collie, 34; Donnybrook, 36; Boyup Brook, 30. These are all much above the usual number of wet days.

The discharge and amount of material carried by these two river systems per day are given in the *Table*. Taking three weeks as the period of maximum flooding and the figures in the *Table*, the following approximate figures for the total load during the flood period are:—

	Tons in three weeks.
Collie river	30,000
Preston river	63,000
Leschenault Estuary, near outlet	16,000

The sampling in Leschenault Estuary needs some explanation; owing to bad weather conditions it was not possible to obtain samples at the outlet of the Estuary into Koombana Bay (see enlarged inset on *Map*) but samples were collected opposite Pig Island about half a mile from the outlet. The figure of 16,000 tons may therefore be slightly on the high side, for some deposition could occur between Pig Island and the outlet.

The Estuary received about 93,000 tons of material from the Collie and Preston rivers; 16,000 tons passed into Koombana Bay and eventually out to sea, leaving 77,000 tons to be deposited in Leschenault Inlet. It is interesting to note that the Swan-Avon river system discharged 863,000 tons of material during the 1926 flood (2).

The figures for the load carried by the Preston river show that it varied considerably. The Preston at the main road bridge (No. 6; for these positions see inset *Map*) carried 970 tons per day; at Glen Iris (No. 9) the load had increased to 3,570 tons, but only 300 tons per day passed through the original channel at Leschenault (No. 7) which used to flood badly every winter before the new channel was cut. The load was 2,740 tons per day in the new channel (No. 8), indicating that about 500 tons per day was being deposited in the new channel.

CONCLUSIONS.

The tabulated results give a number of figures which are of interest because they give some quantitative idea of the work being done by the streams observed. The quantity of material carried by the North Irwin, in grammes per litre, is many times greater than that carried by any other stream so far examined in the South-West. This may be due partly to the bareness of the country at the time of the exceptional rains, partly to the fact that during the summer the stream bed is dry except for a pool or two; therefore there is abundant fine material mixed with sand, pebbles, and angular flat pieces of rock which must also have been rolled along the bed but did not enter into the samples of water collected. The rate of flow is about the average rate of flow of the other streams. Much of the material may not have been transported very far. The amount of material carried by the North Irwin may be of an order characteristic of the rivers in the North-West, for which we have no information at present.

The Collie and Preston rivers carry a greater load, when in flood, than does the Swan; such a stream as the Chittering, which is almost wholly in the Pre-Cambrian rocks, carries a very small load.

It is evident that a great part of the load of these rivers seems to be picked up from the more easily eroded soils and sands of the coastal plain, and does not come directly from the higher Pre-Cambrian country. The actual fall of any of these rivers is not great; that for the Swan-Avon and for the Collie and Preston rivers cannot be more than 1,000 feet.

The amount removed by the Collie and Preston systems during the flood period per square mile of drainage area is 67 tons. The world's average per year per square mile is 62.3 tons (1).

The results show that the rate of erosion in this part of south-western Australia approaches the world average for years of unusually heavy rainfall, but as these only occur once in every six to eight years, the true rate of erosion is many times less than in countries with a better rainfall and greater heights which give the rivers more eroding power.

Unfortunately there are no records of the usual winter loads of these streams for comparison with the figures given here, which, as explained above, must be regarded as very approximate, and as under-estimates. Observations (without measurements) seem to indicate that it is only in times of abnormal flood that much material is removed.

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